Searching for Cool Dust in the Mid-to-Far Infrared: the Mass Loss Histories of the Hypergiants μ Cep, VY CMa, IRC +10420 & ρ Cas

Shenoy, D. P., Humphreys, R. M., Jones, T. J., Marengo, M., Gehrz, R. D., Helton, L. A., Hoffmann, W., Skemer, A., & Hinz, P., (accepted by AJ, in press)
http://arxiv.org/abs/1512.01529

Reporting results from SOFIA Cycle 2 Program # 02_0031 (PI: R. M. Humphreys)

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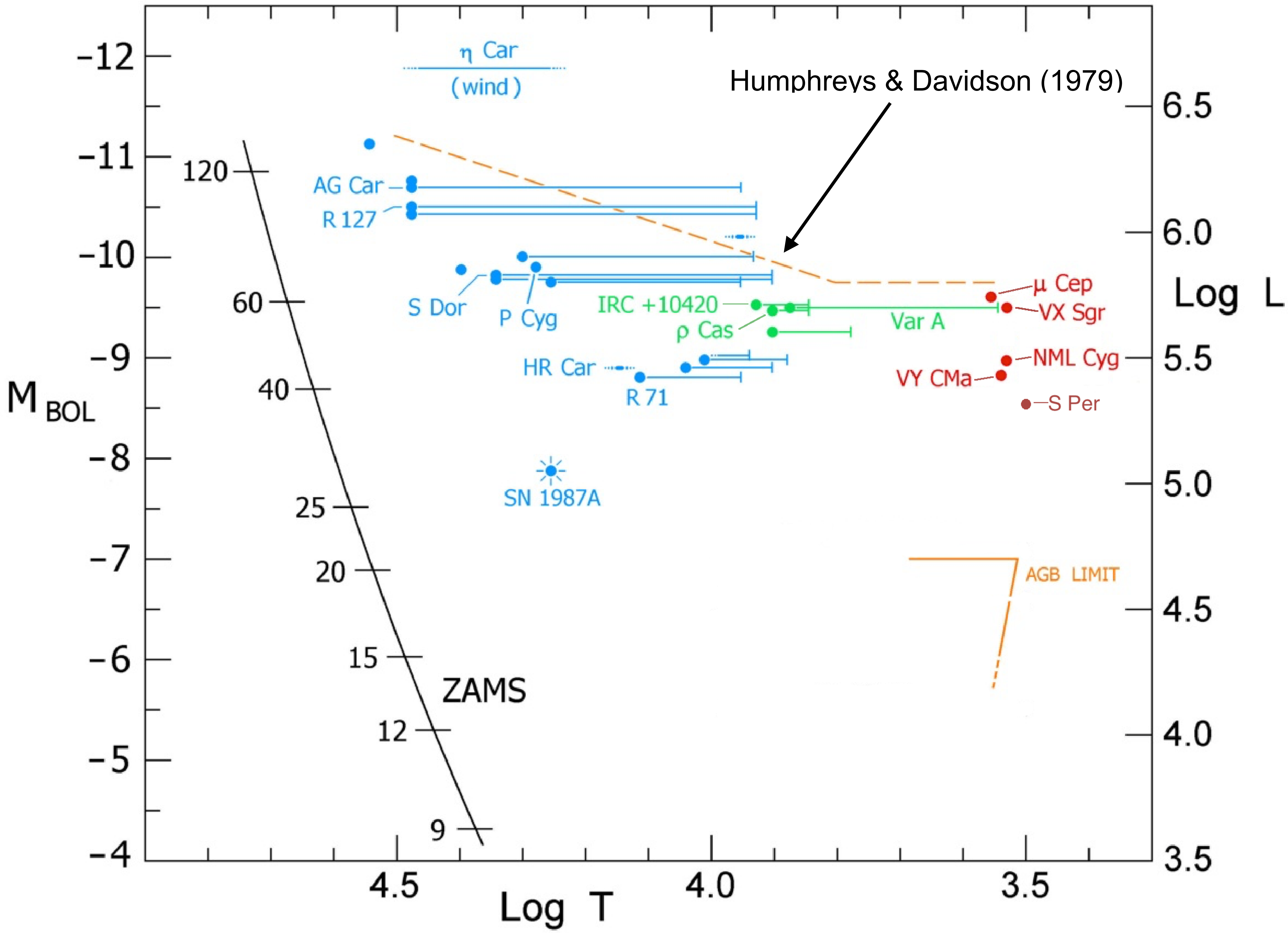
LMIRCam team (Skrutskie et al. 2010)
MIRAC team (Hoffmann et al. 1998; Hinz et al. 2000)

February 3, 2016

Outline

1. Intro & Motivations
2. Multi-Wavelength IR obs
3. RSGs: μ Cep & VY CMa
4. YSGs: IRC +10420 & rho Cas
5. Summary and Future Work

Upper End of HR Diagram

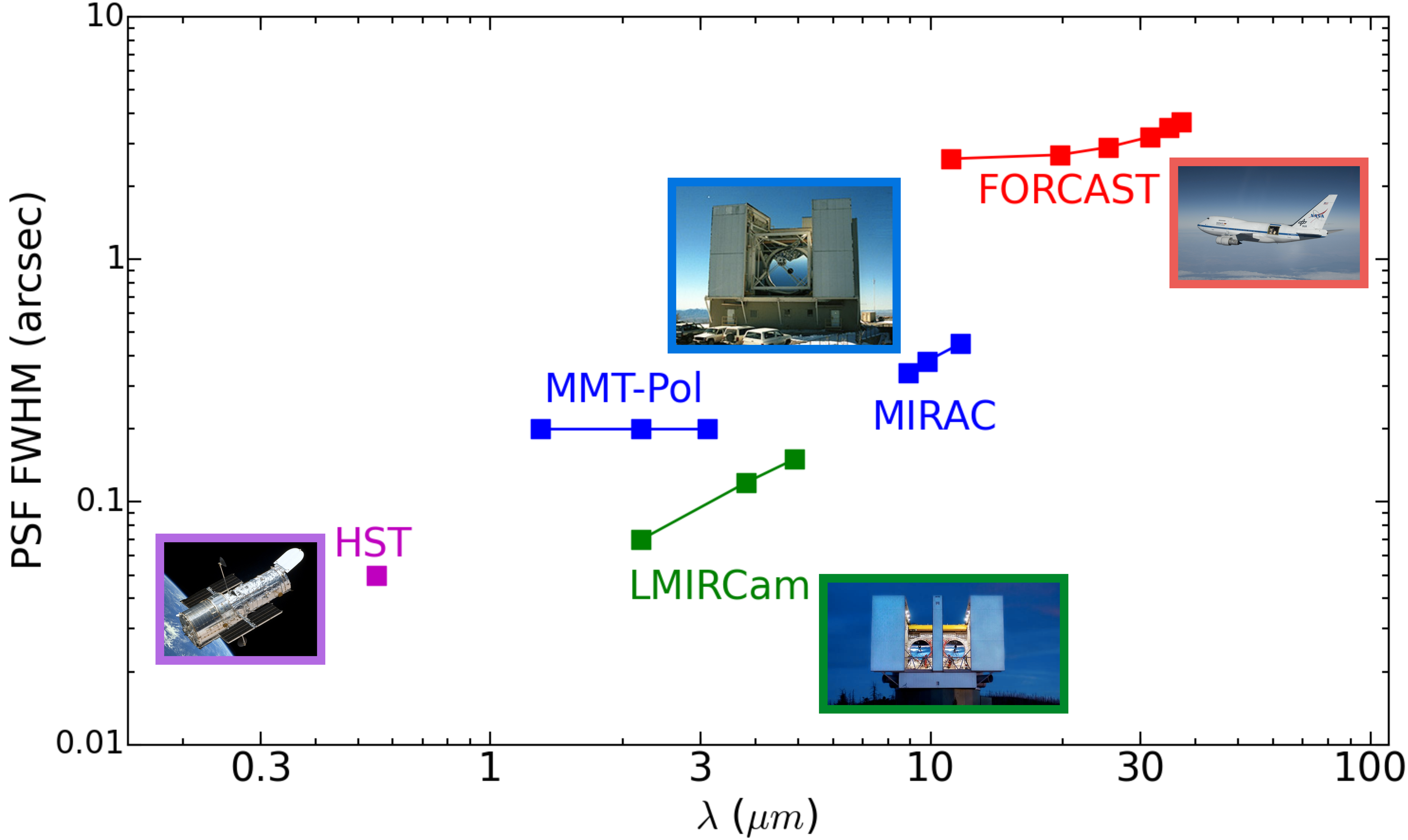


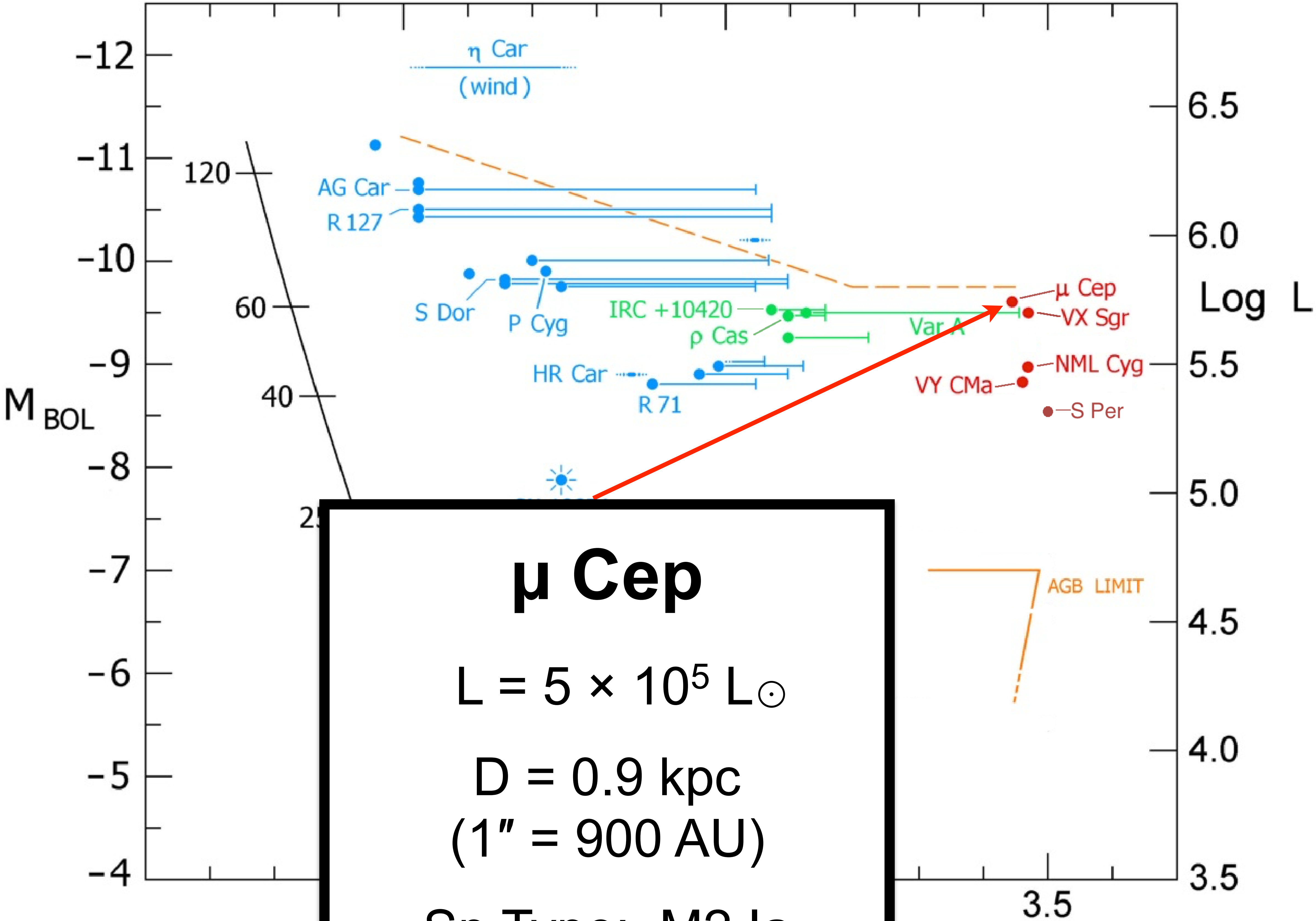
Motivations

(1) Study hypergiants' poorly understood **episodic** mass-loss during the RSG stage and post-RSG stages using new capabilities in near-IR imaging and polarimetry.

(2) Combine the study of their close environments with mid/far-IR imaging of their larger environments to determine their mass-loss histories.

Angular Resolution of Instruments Used





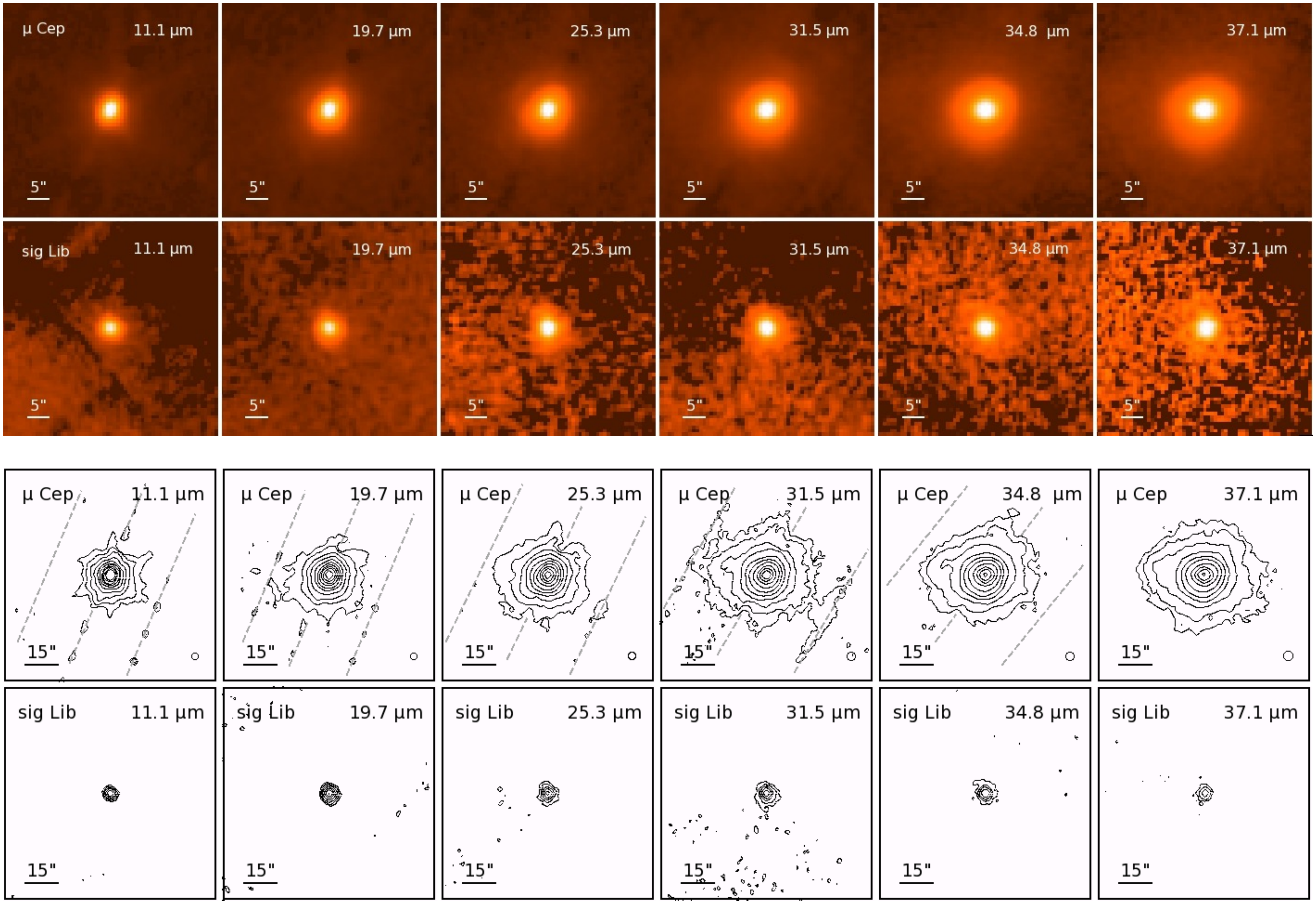
μ Cep

$L = 5 \times 10^5 L_\odot$

D = 0.9 kpc
(1″ = 900 AU)

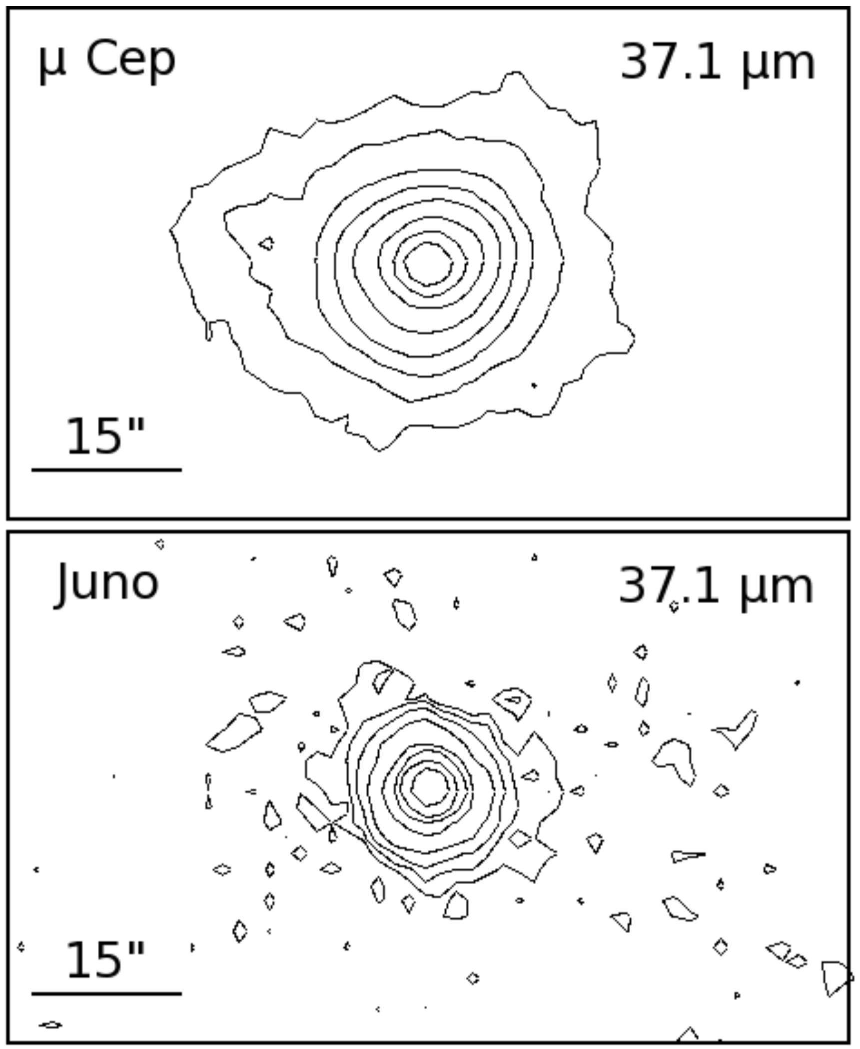
Sp Type: M2 Ia

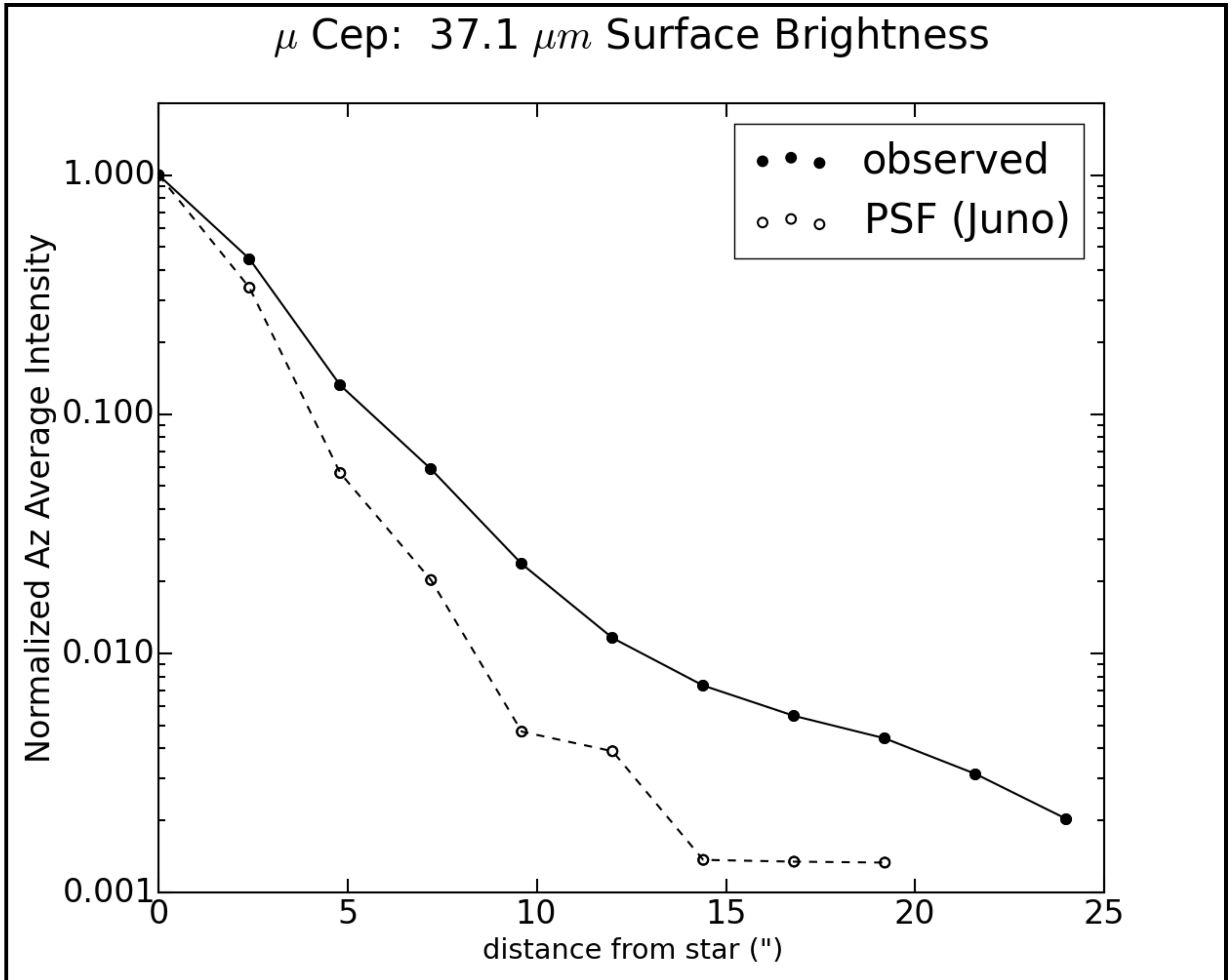
μ Cep: SOFIA / FORCAST (11 - 37 μm)



Shenoy et al. (2016). SOFIA Program 02_0031 (PI: R. M. Humphreys)

μ Cep: SOFIA / FORCAST (11 - 37 μm)

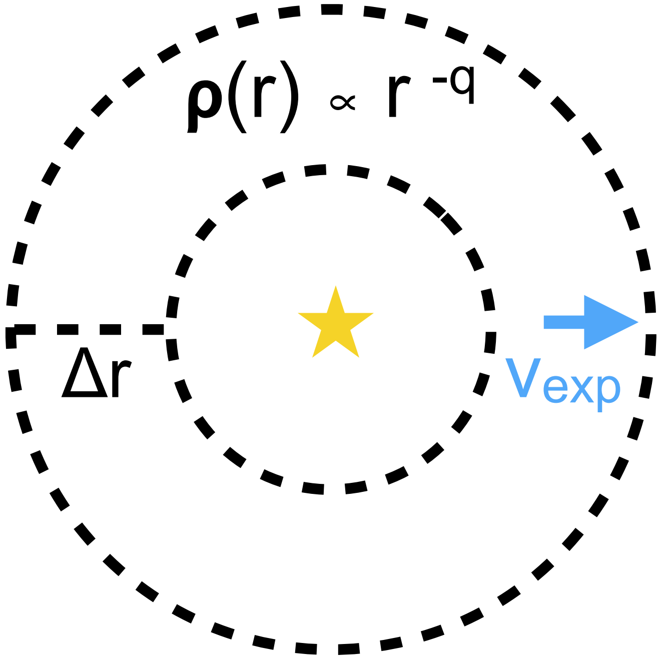




Shenoy et al. (2016)

Mass-Loss History

DUSTY - 1D rad trans
(Ivezic & Elitzur, 1997)



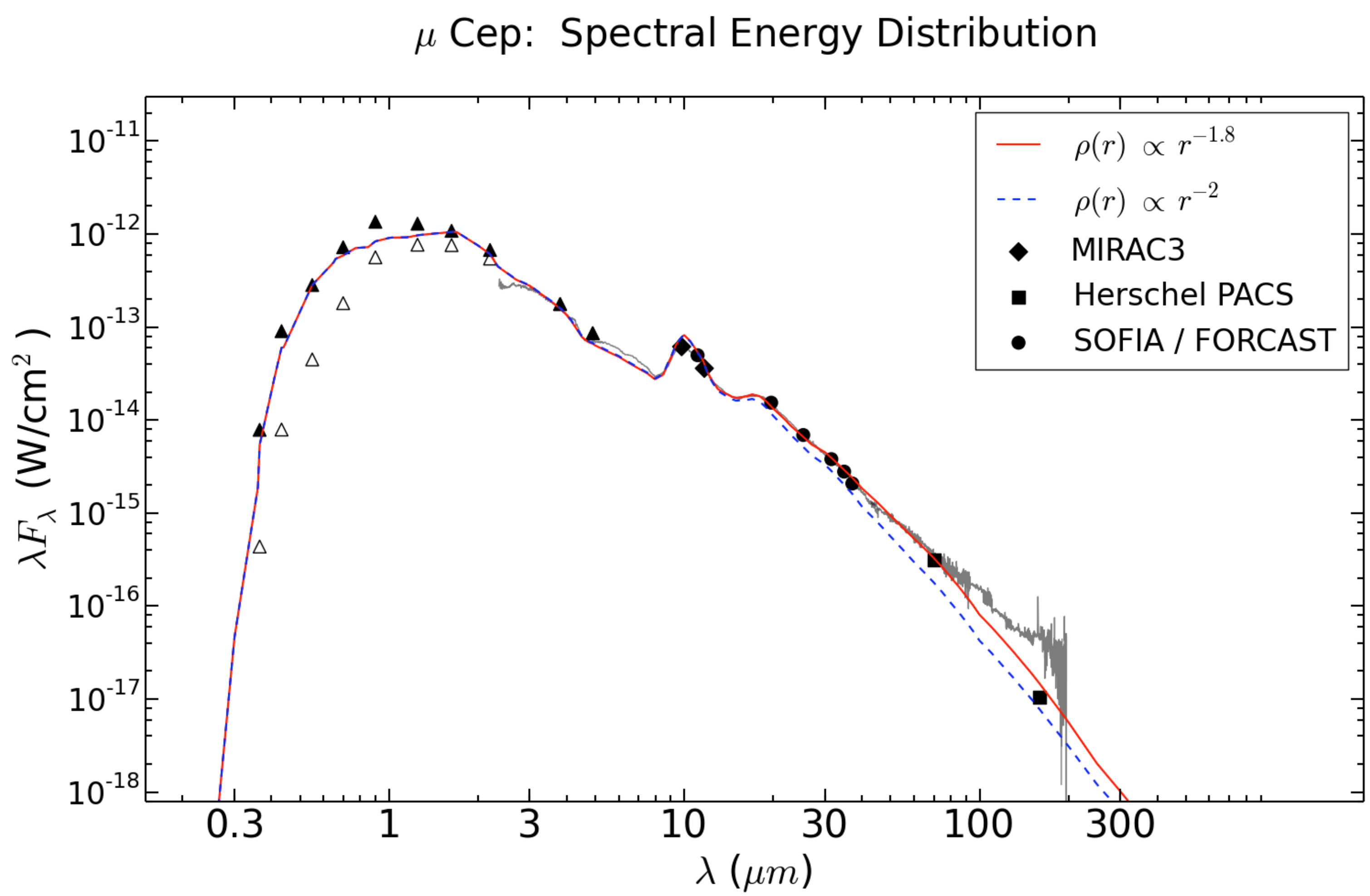
$$\dot{M}(t) = g_d \cdot 4\pi r^2 \cdot \rho(r) \cdot v_{exp}$$

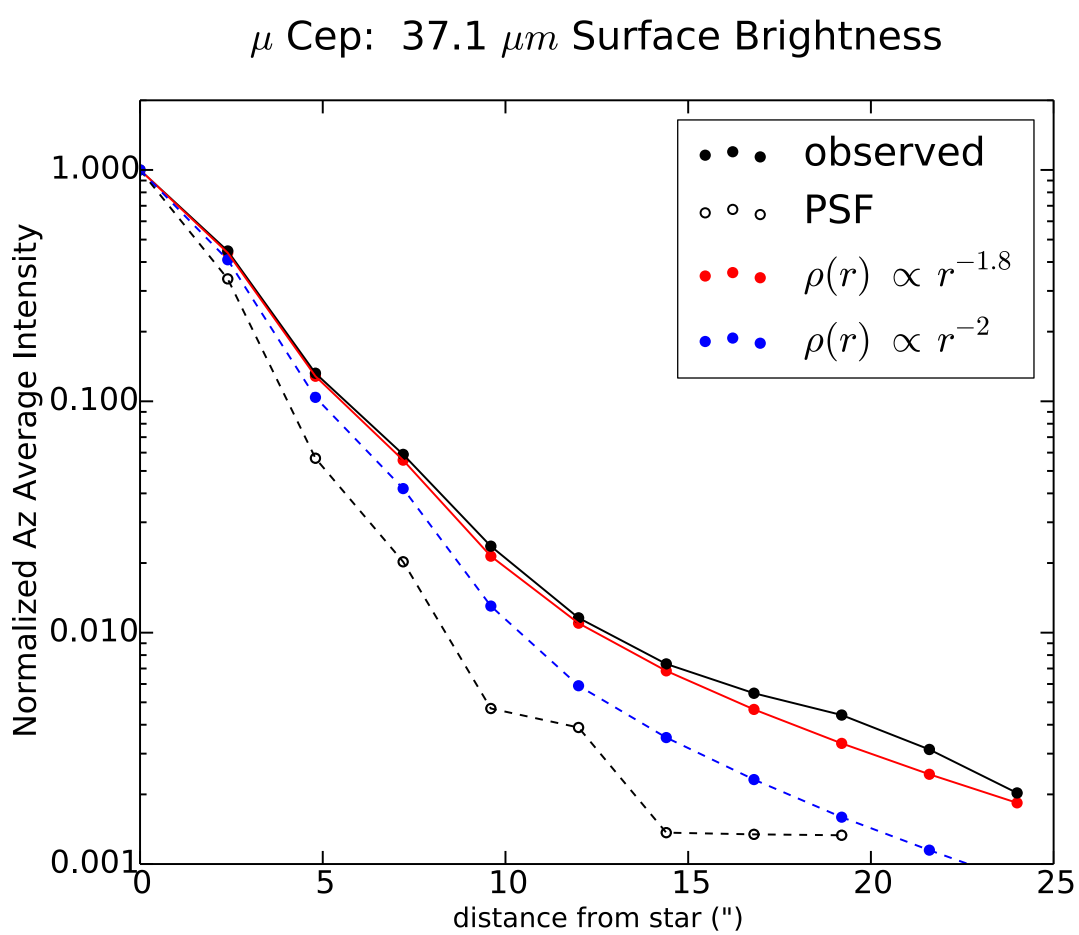
$$\rho(r) \propto r^{-q} = \begin{cases} q = 2 \longrightarrow \dot{M} = \text{const.} \\ q < 2 \longrightarrow \dot{M} \text{ decreasing} \end{cases}$$

$$M = \int \rho(r) \cdot 4\pi r^2 dr \quad ; \quad \Delta t = \Delta r \ / \ \langle v_{exp} \rangle$$

$$\langle \dot{M} \rangle = M \ / \ \Delta t$$

μ Cep: Mass-Loss History

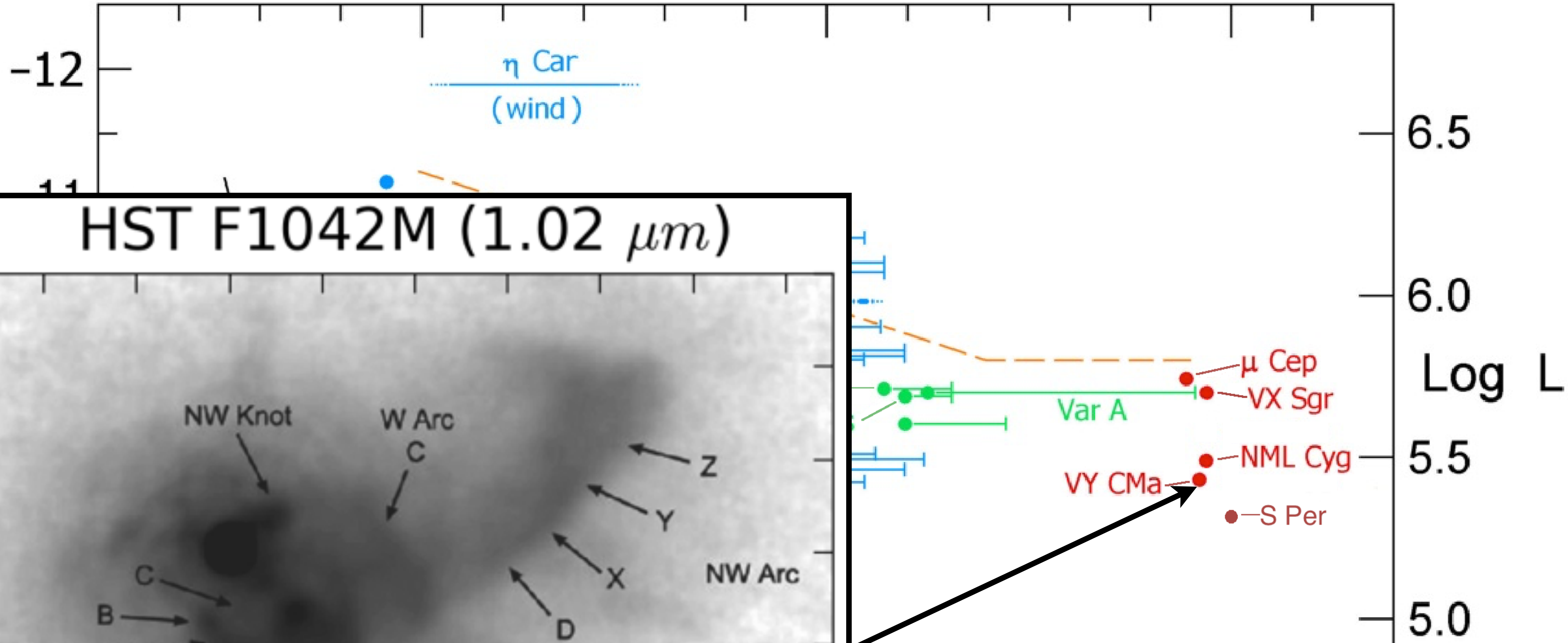


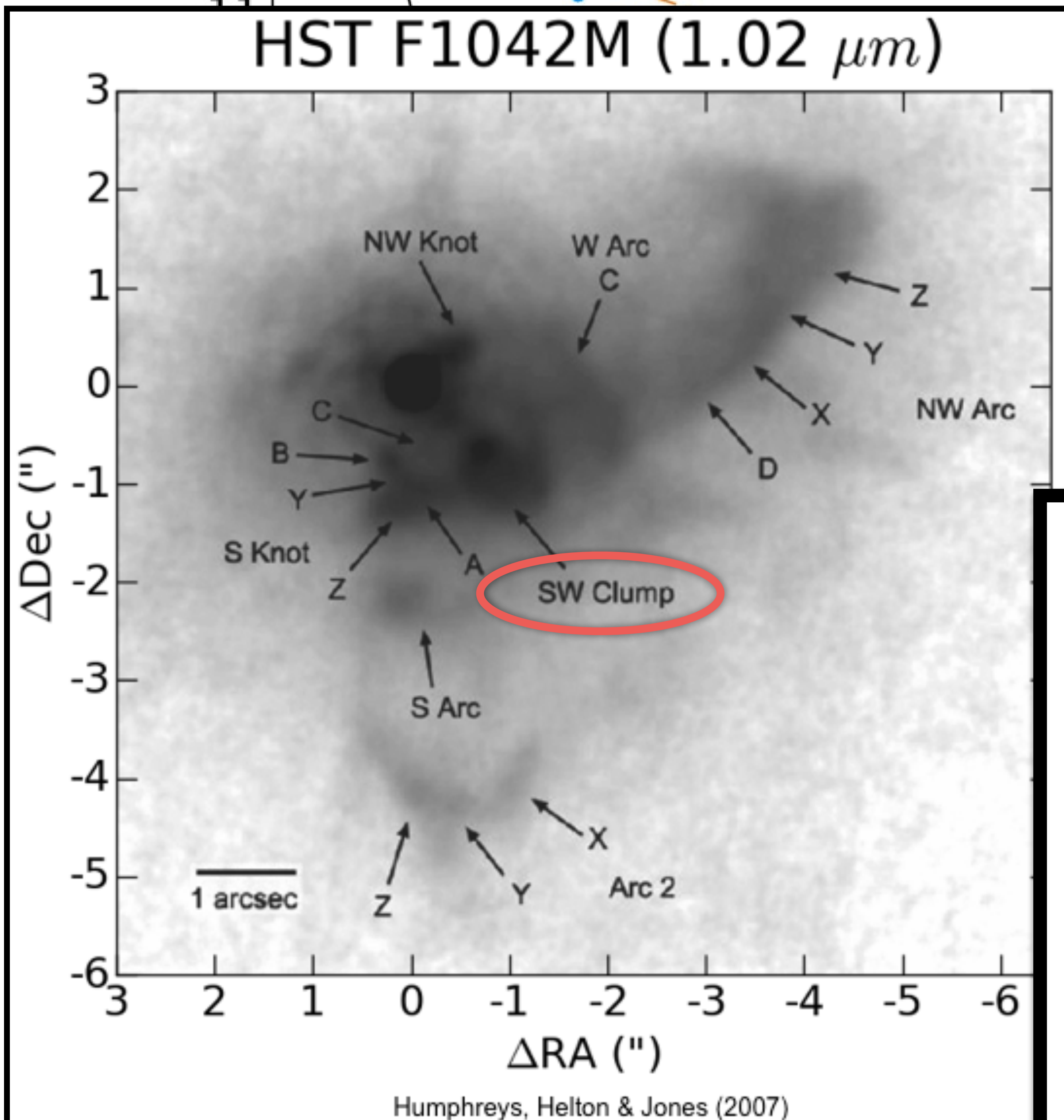


$1 \times 10^{-6}\ M_\odot$ / yr < $\dot{M}(t)$ < $5 \times 10^{-6}\ M_\odot$ / yr

$\langle \dot{M} \rangle \approx 4 \times 10^{-6}\ M_\odot$ / yr

Shenoy et al. (2016)





Humphreys, Helton & Jones (2007)

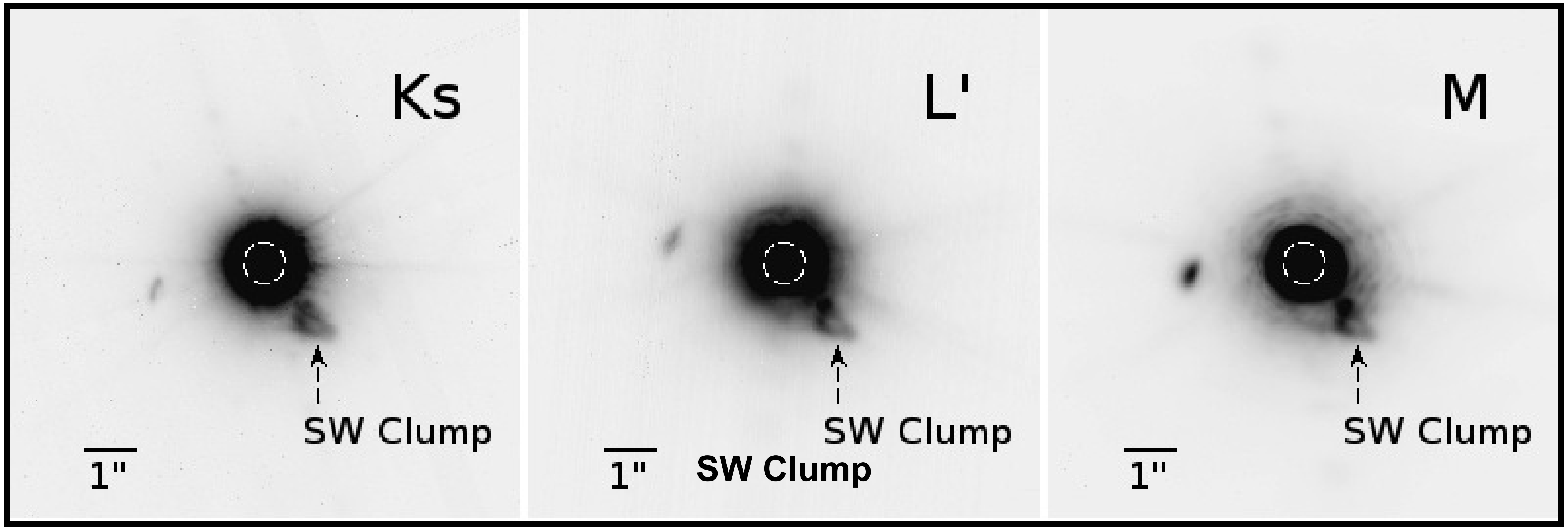
VY CMa

$L = 2.7 \times 10^5 L_\odot$

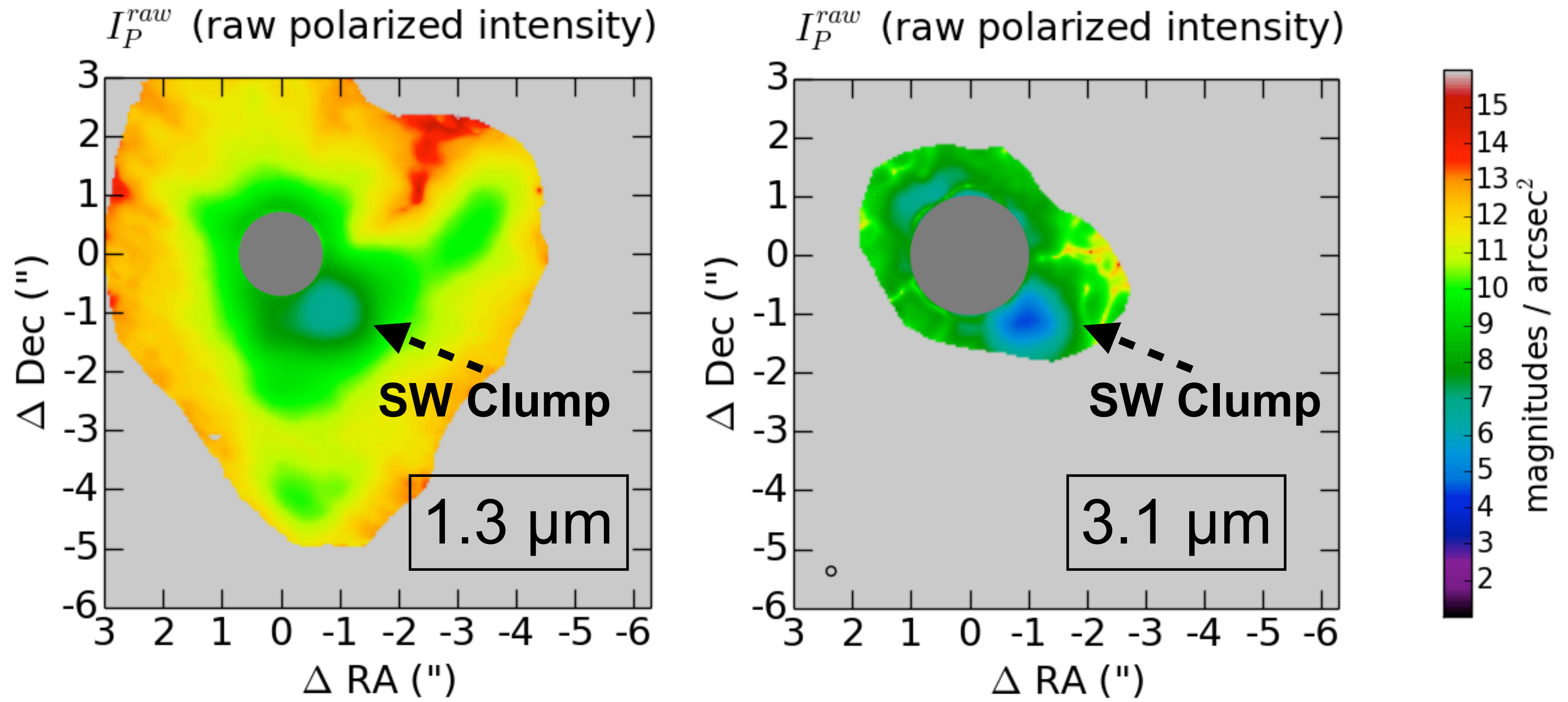
D = 1.2 kpc
(1″ = 1200 AU)

Sp Type: M4 − M5 Ia

VY CMa: Near-IR & Polarimetry



Shenoy et al. (2013)



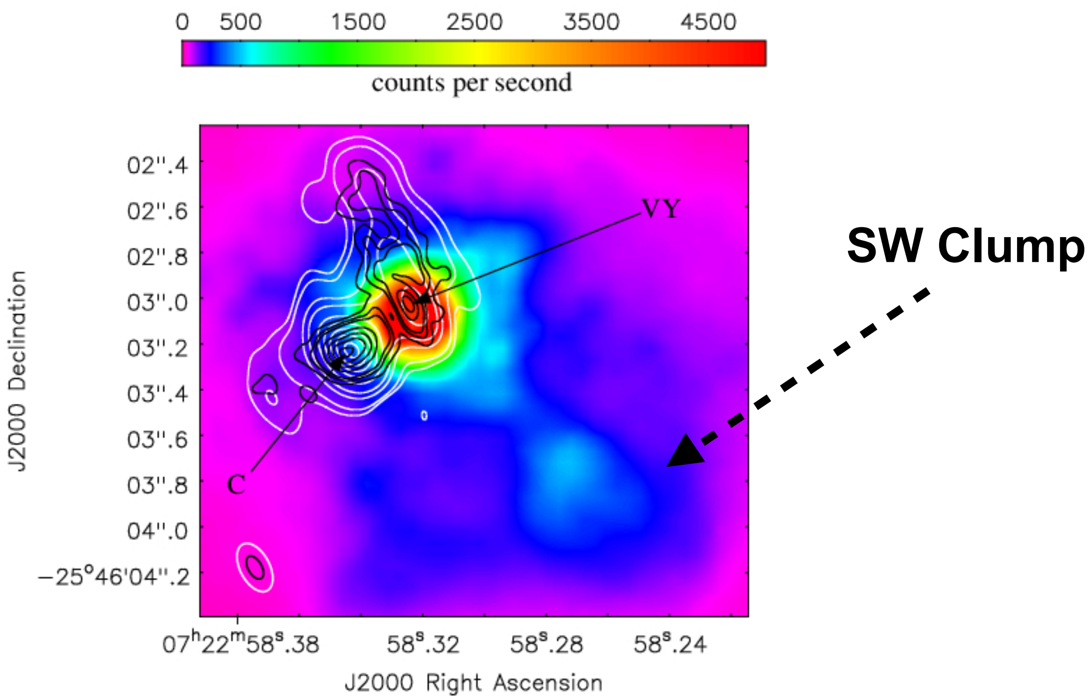
Shenoy, Jones, Packham & Lopez-Rodriguez (2015)

$\tau_{scat} > 1$

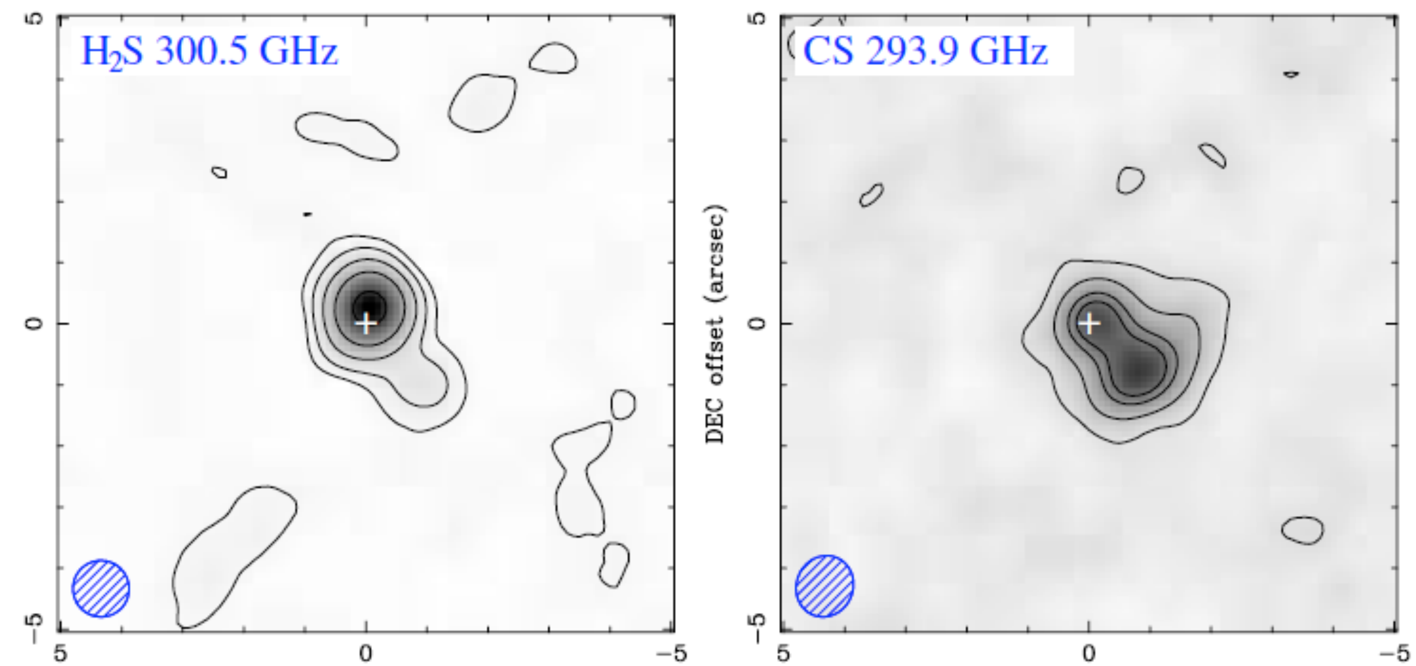
$\langle a \rangle \approx 0.3\ \mu m$

$M_{tot} > 5 \times 10^{-3}\ M_\odot$

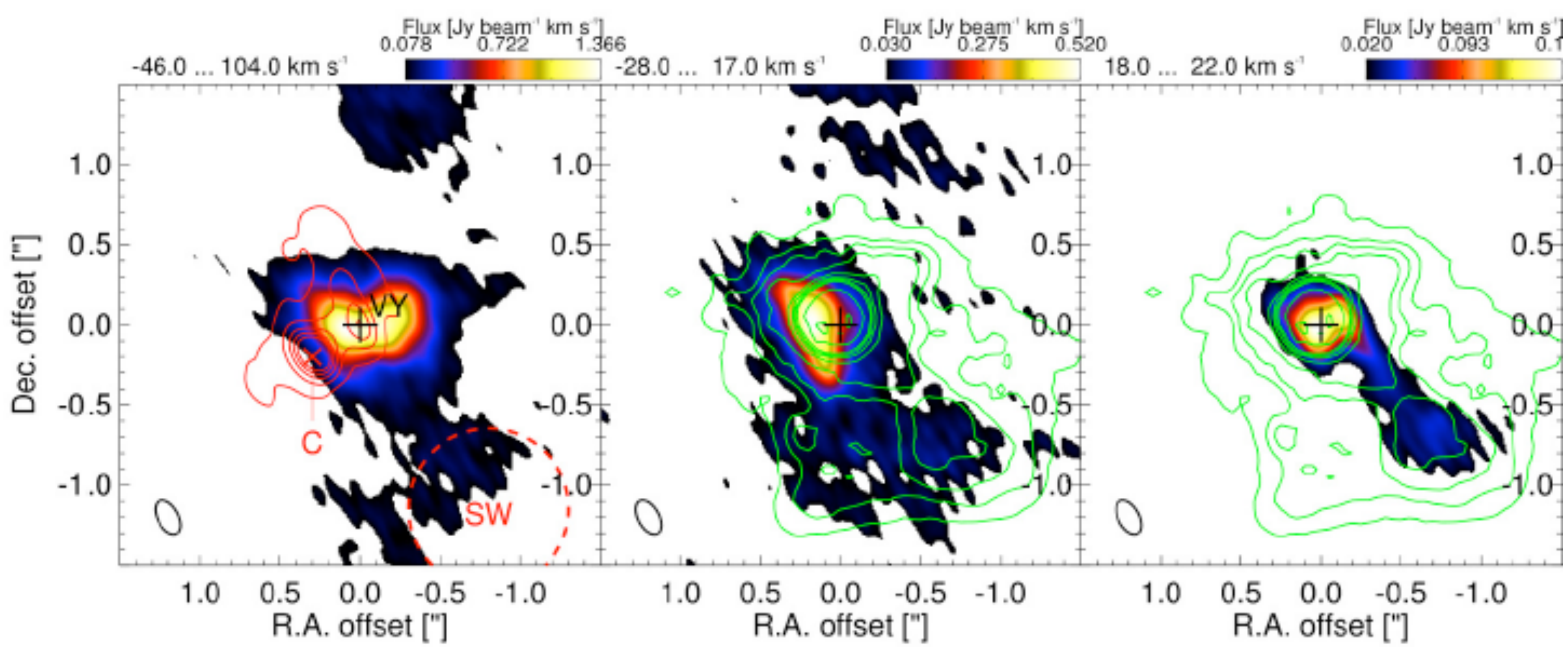
VY CMa: Sub-MM



321 & 658 GHz: O'Gorman et al. (2015), A&A 573, L1

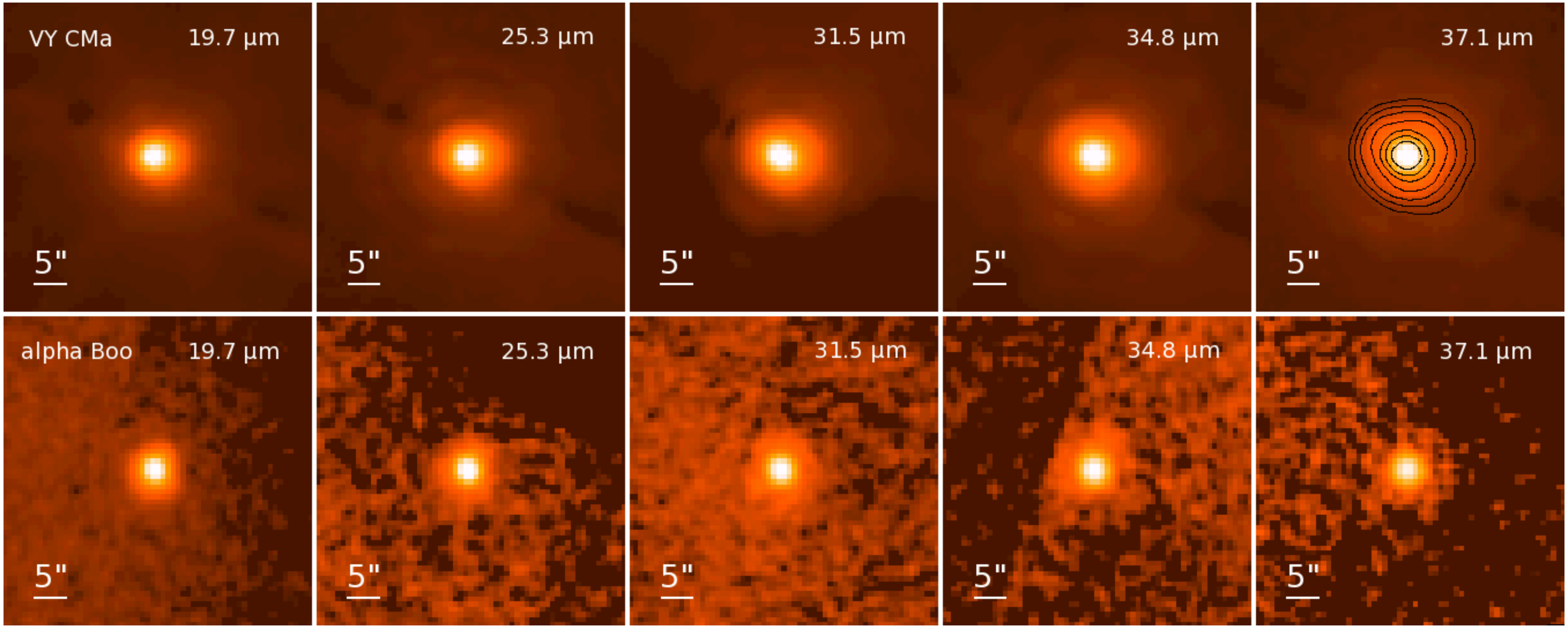


H_2S & CS: Kaminski et al. (2013), ApJS 209, 38



TiO_2 @ 312 - 314 GHz: de Beck et al. (2015), arXiv:1506.0081v1

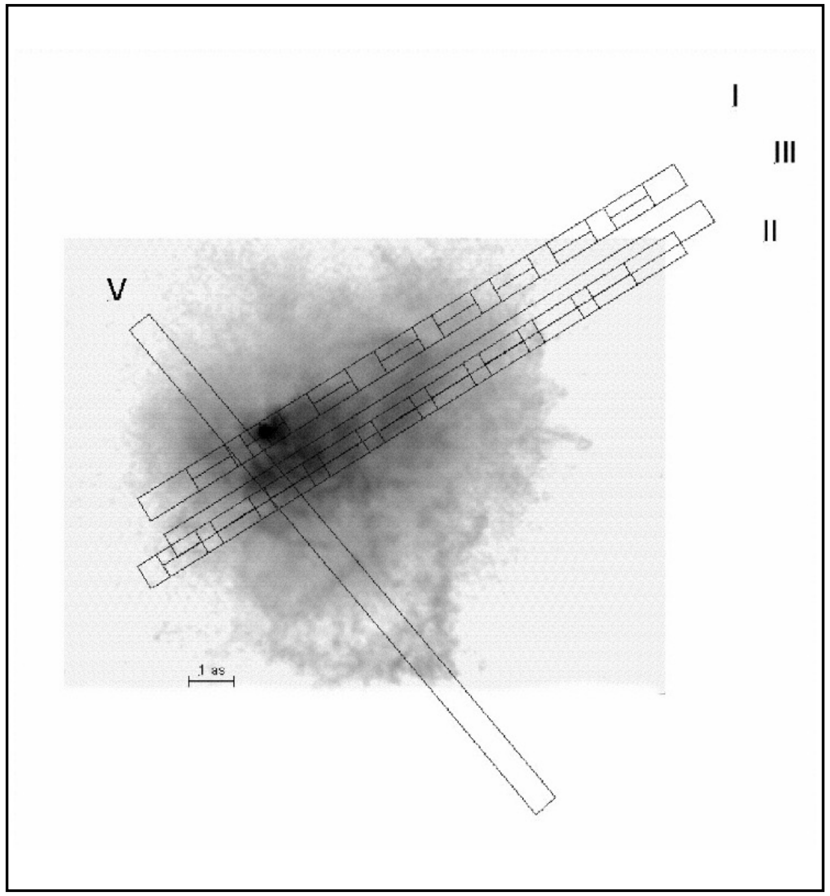
VY CMa: SOFIA / FORCAST (20 - 37 μm)



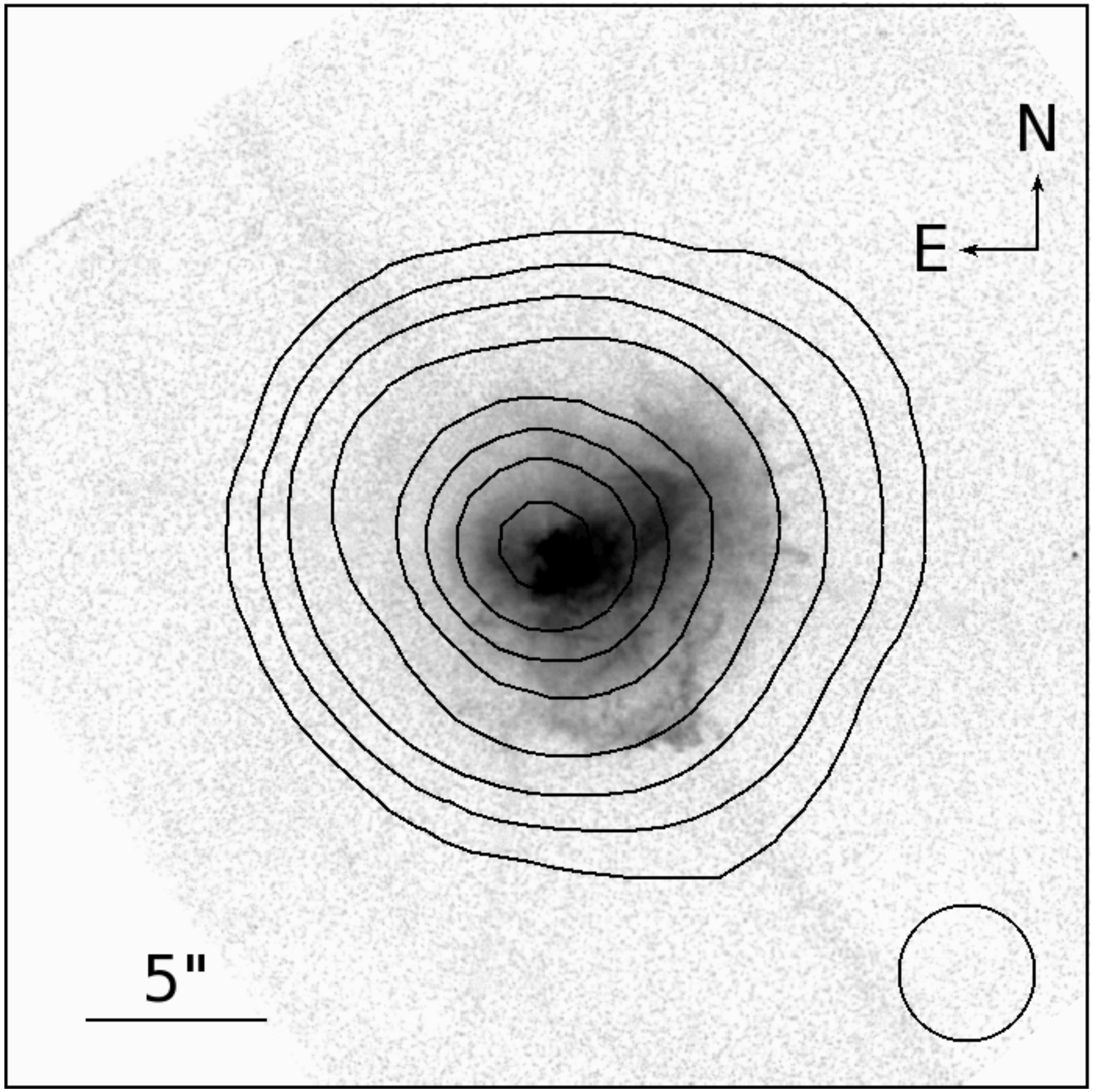
Shenoy et al. (2016). SOFIA Program 02_0031 (PI: R. M. Humphreys)

VY CMa: SOFIA / FORCAST (20 - 37 μm)

Keck / HIRES slits on
HST / WFPC2 image

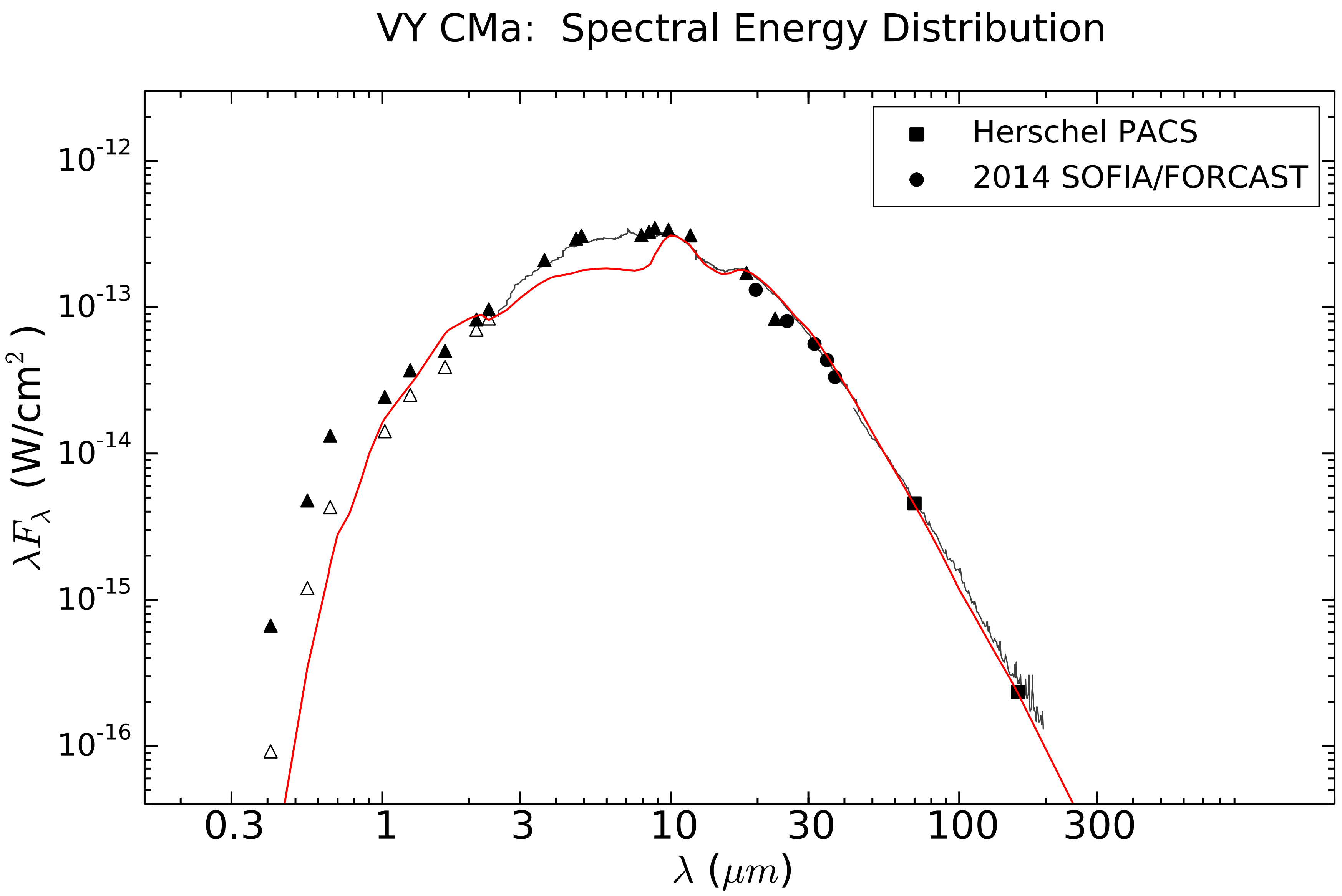


Humphreys, Davidson,
Ruch & Wallerstein (2005)



Shenoy et al. (2016)

VY CMa: Average Mass Loss Rate



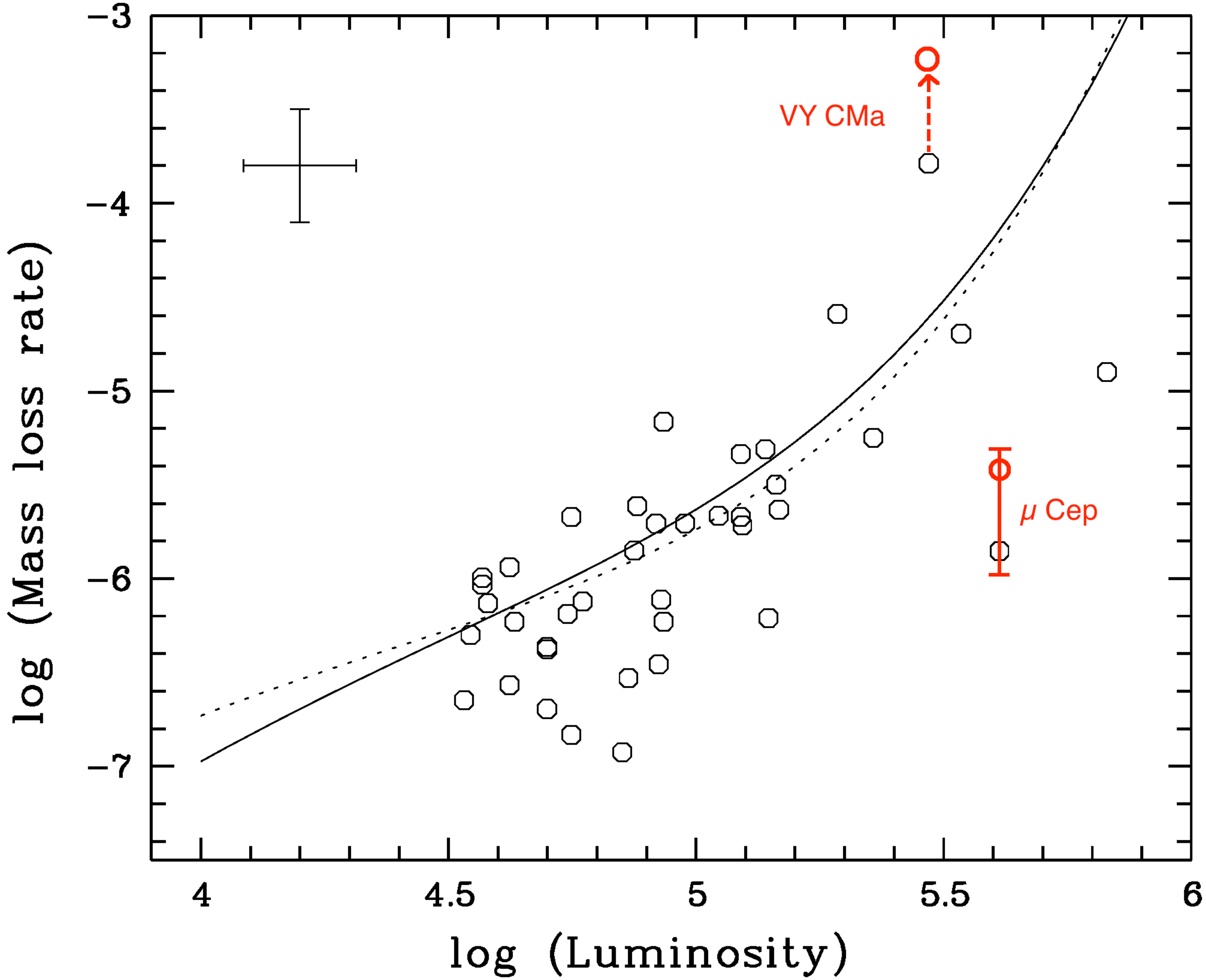
$\langle \dot{M} \rangle \approx 6 \times 10^{-4}\ M_\odot$ / yr

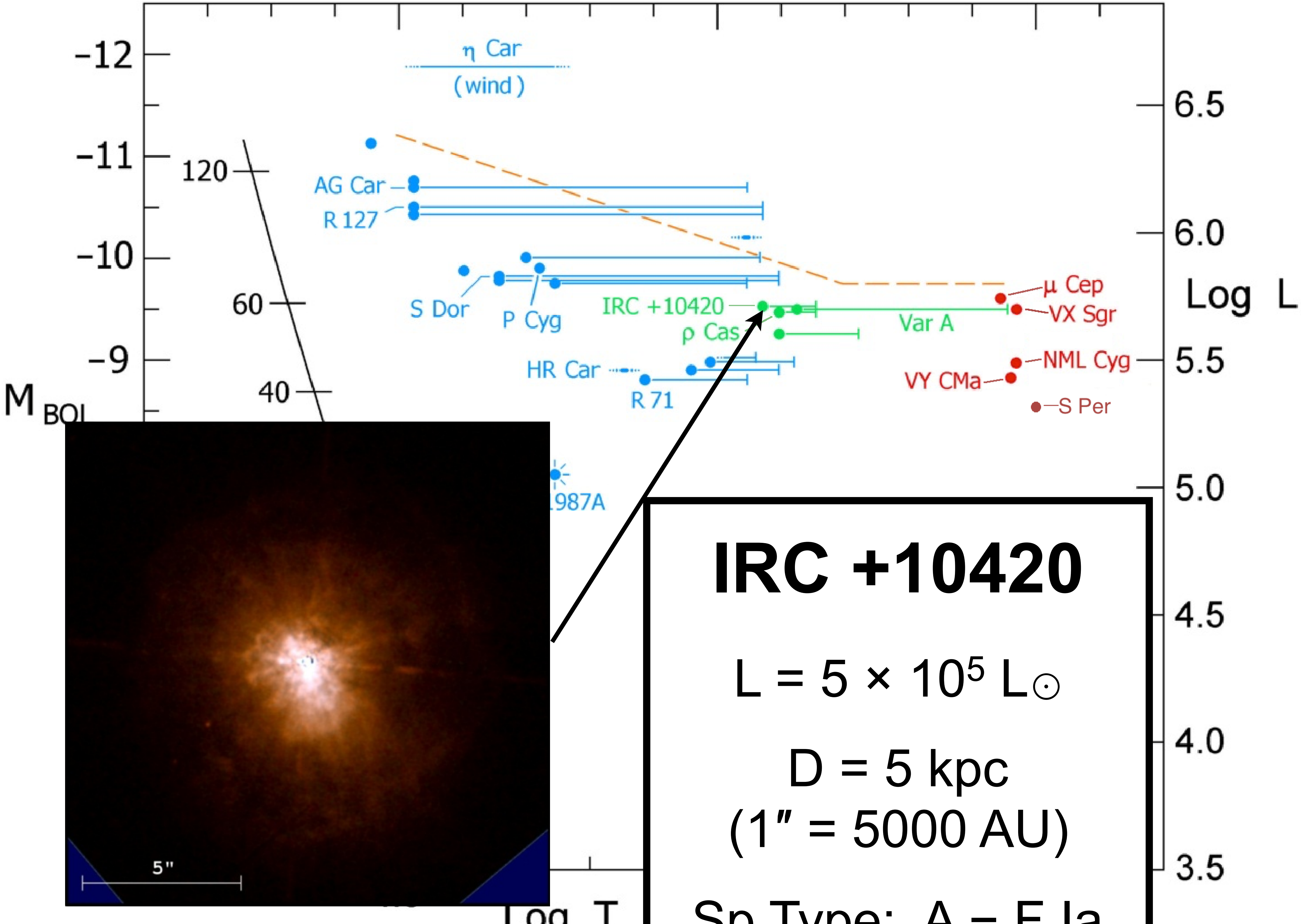
for t_{shell} age ~ 1200 yr

Shenoy et al. (2016)

RSG Mass Loss Rates - Comparison

Adapted from Fig. 2 of Mauron & Josselin (2011)





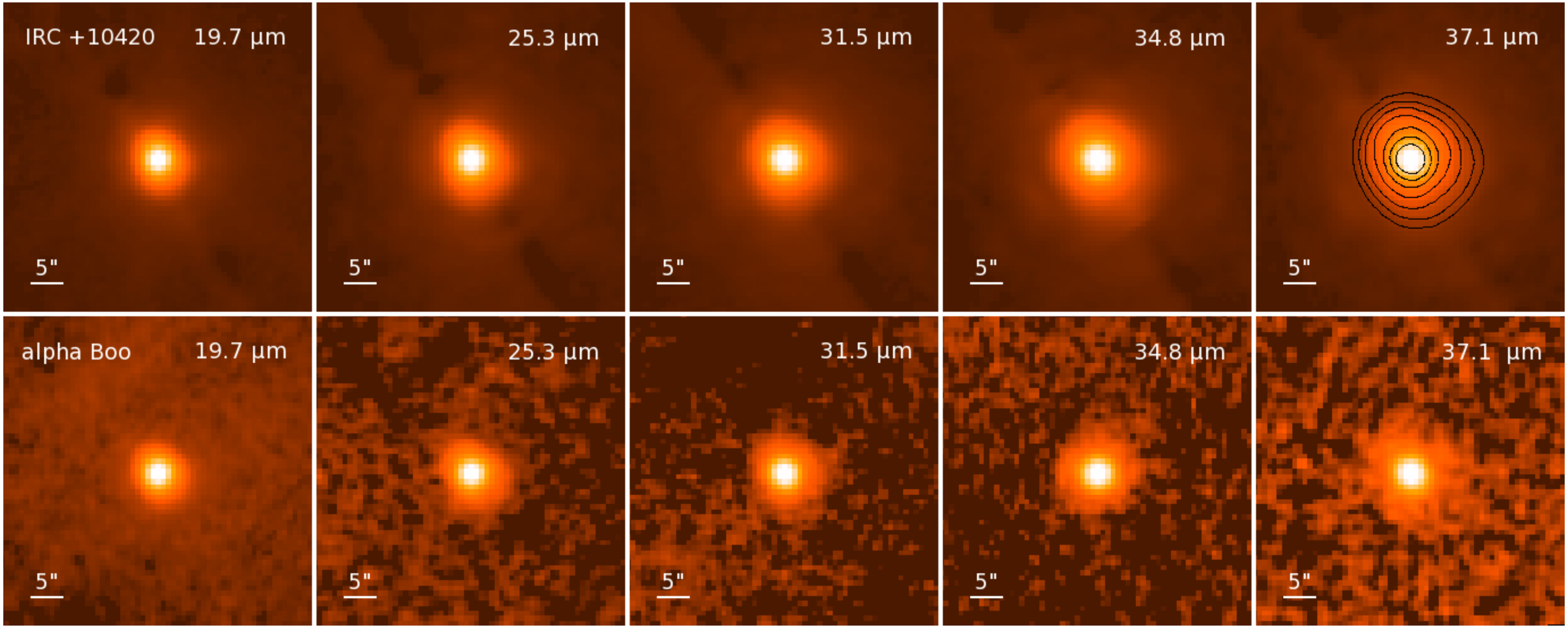
IRC +10420

L = 5 × 10^5 $L_\odot$

D = 5 kpc
(1″ = 5000 AU)

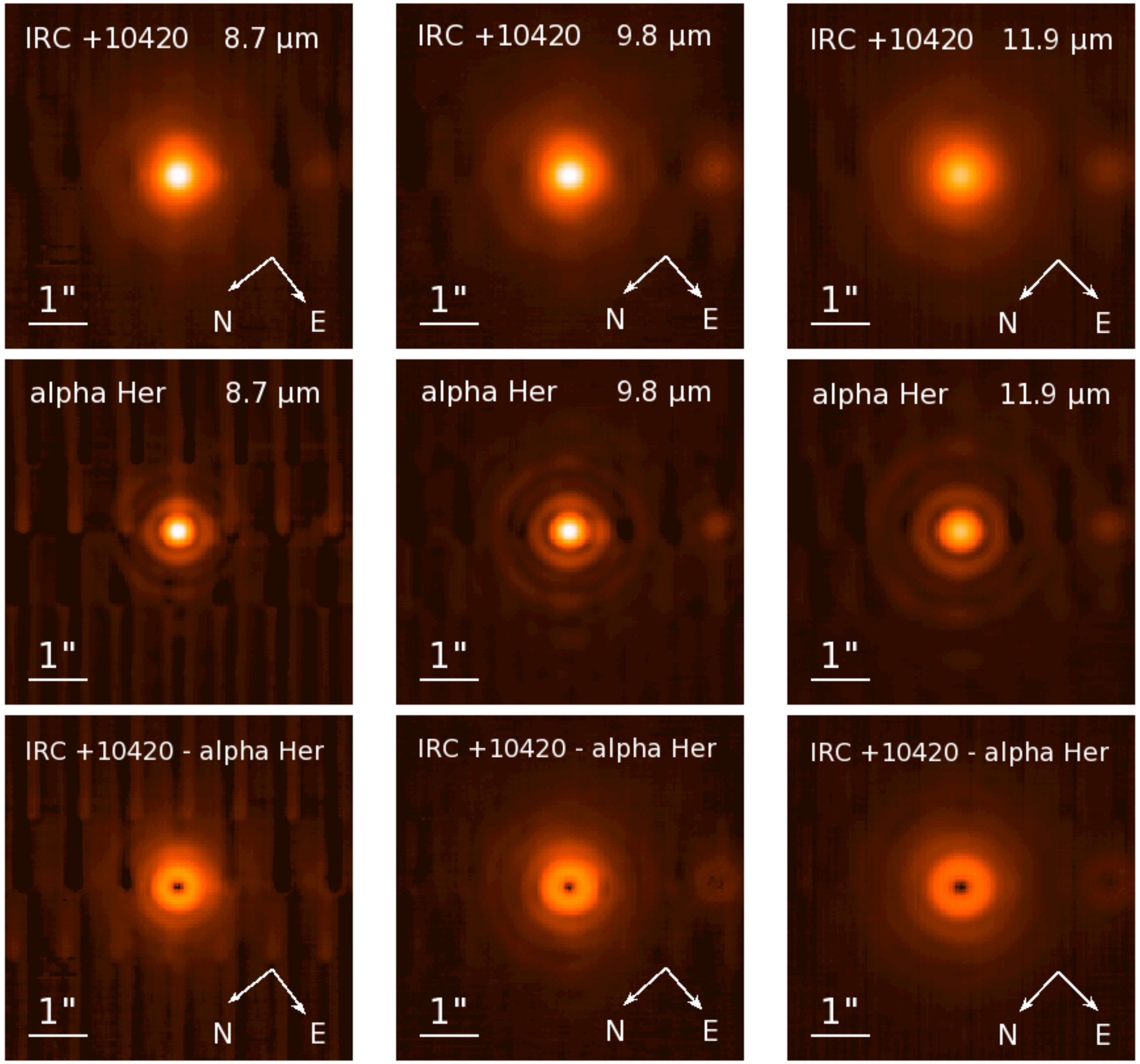
Sp Type: A − F Ia

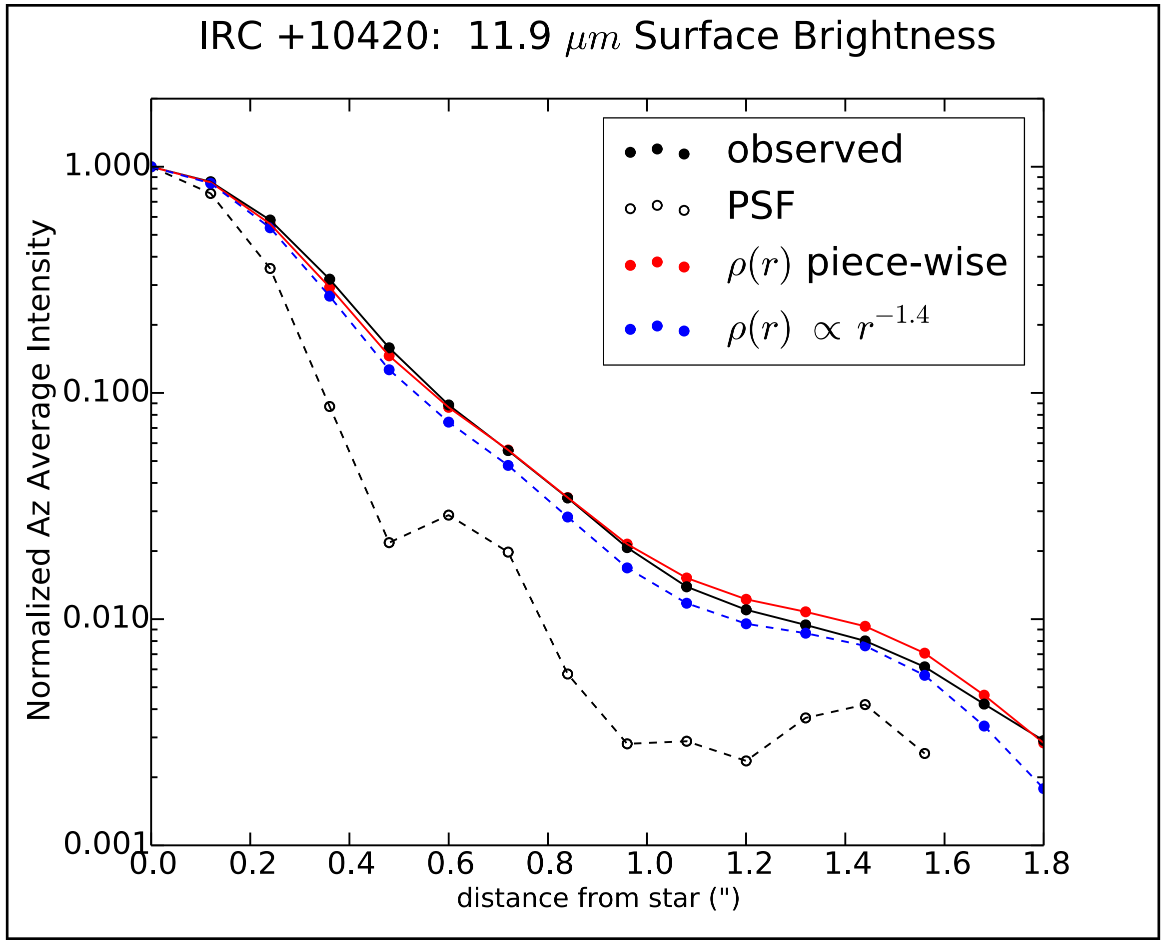
IRC +10420: SOFIA / FORCAST (20 - 37 μm)



Shenoy et al. (2016). SOFIA Program 02_0031 (PI: R. M. Humphreys)

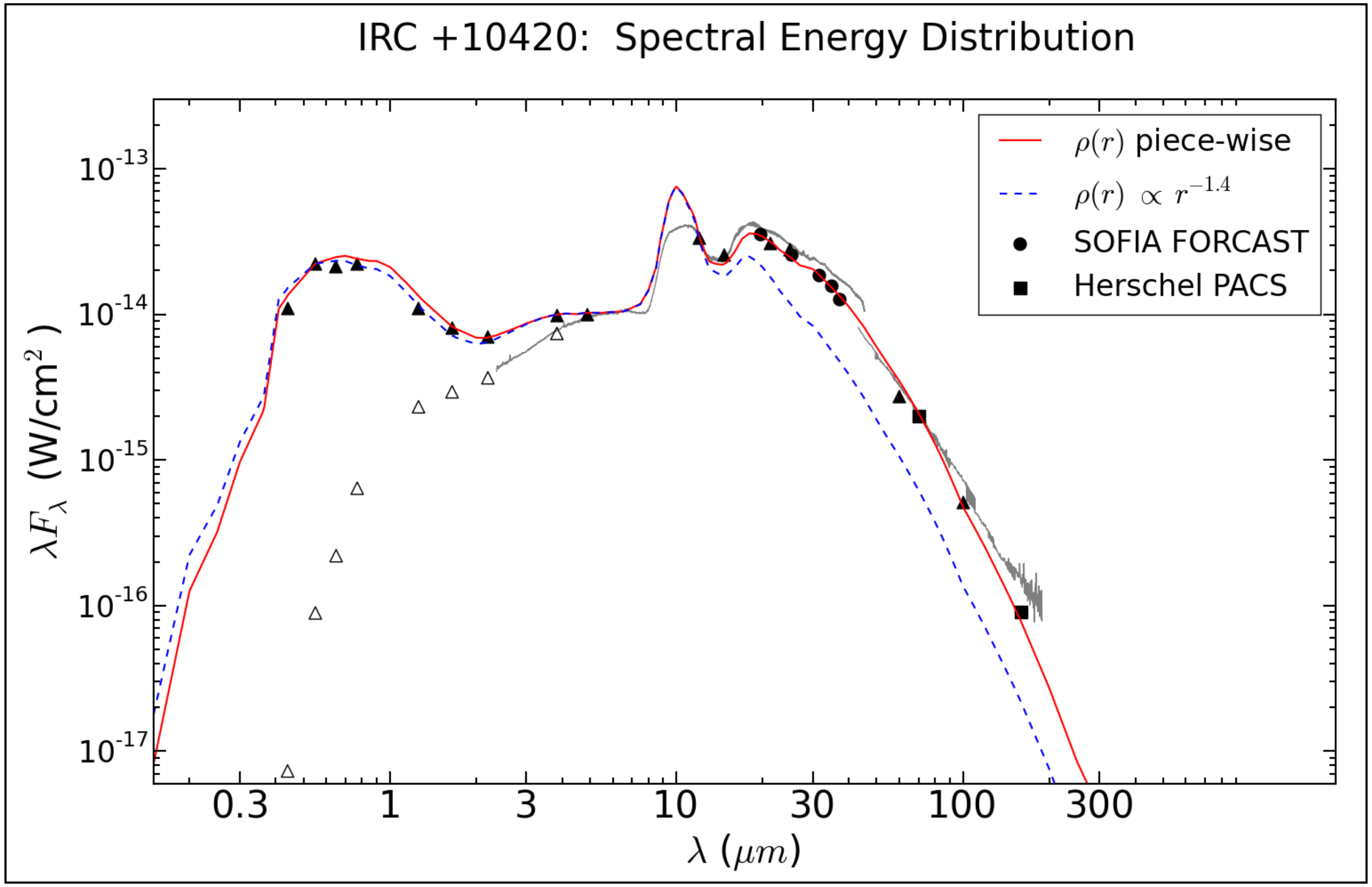
IRC +10420: MMT/MIRAC (8 - 12 μm)

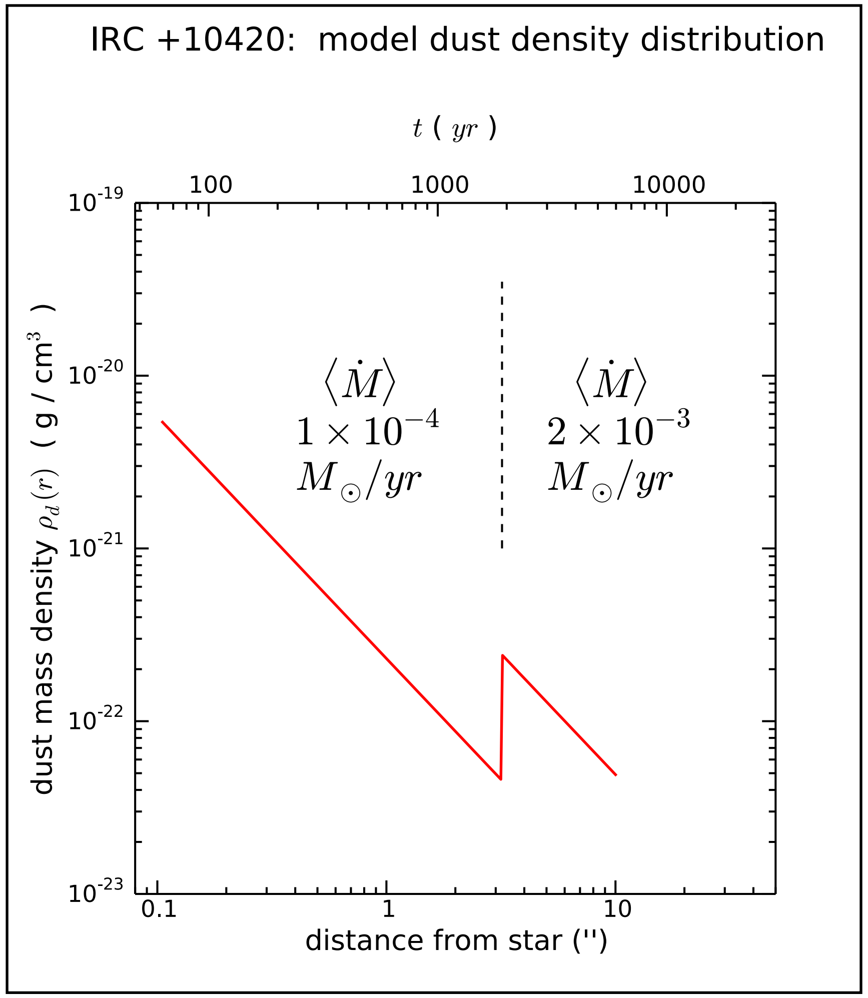




Shenoy et al. (2016)

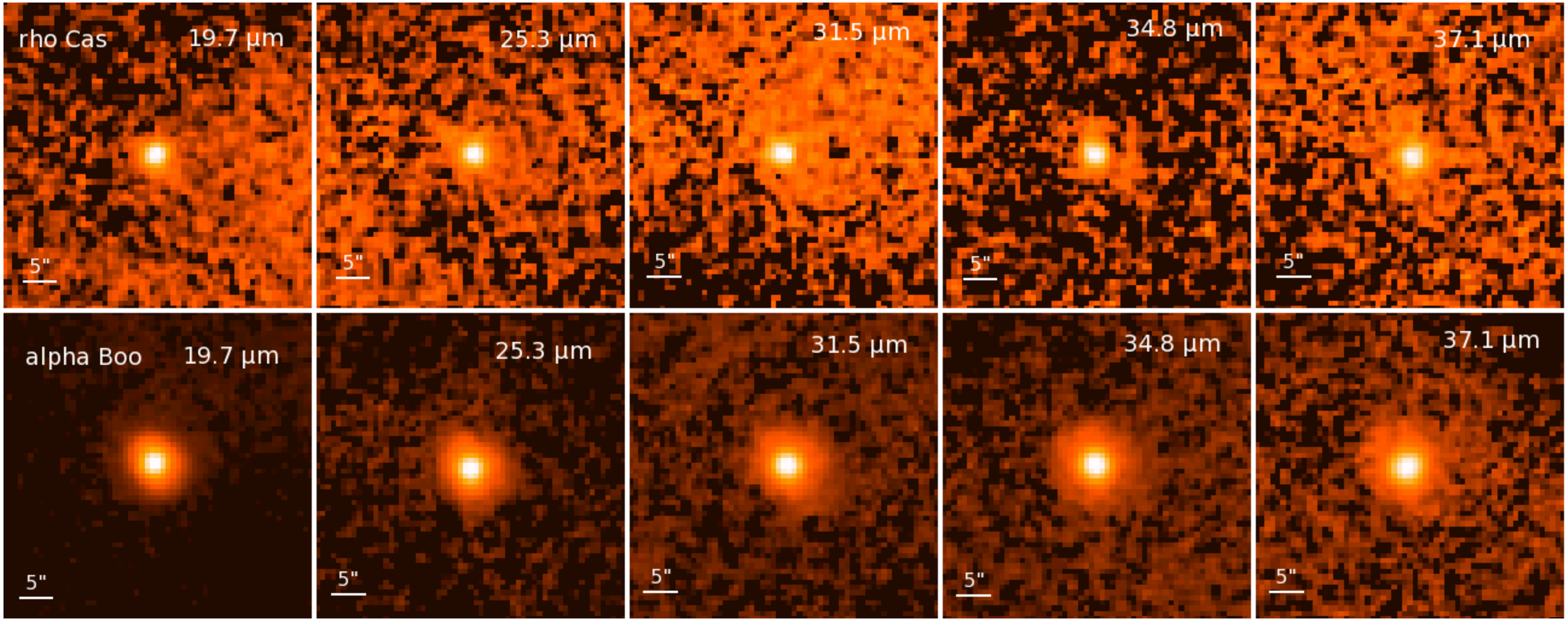
IRC +10420: Mass-Loss History





Shenoy et al. (2016)

ρ Cas: SOFIA / FORCAST (20 - 37 μm)



Shenoy et al. (2016). SOFIA Program 02_0031 (PI: R. M. Humphreys)

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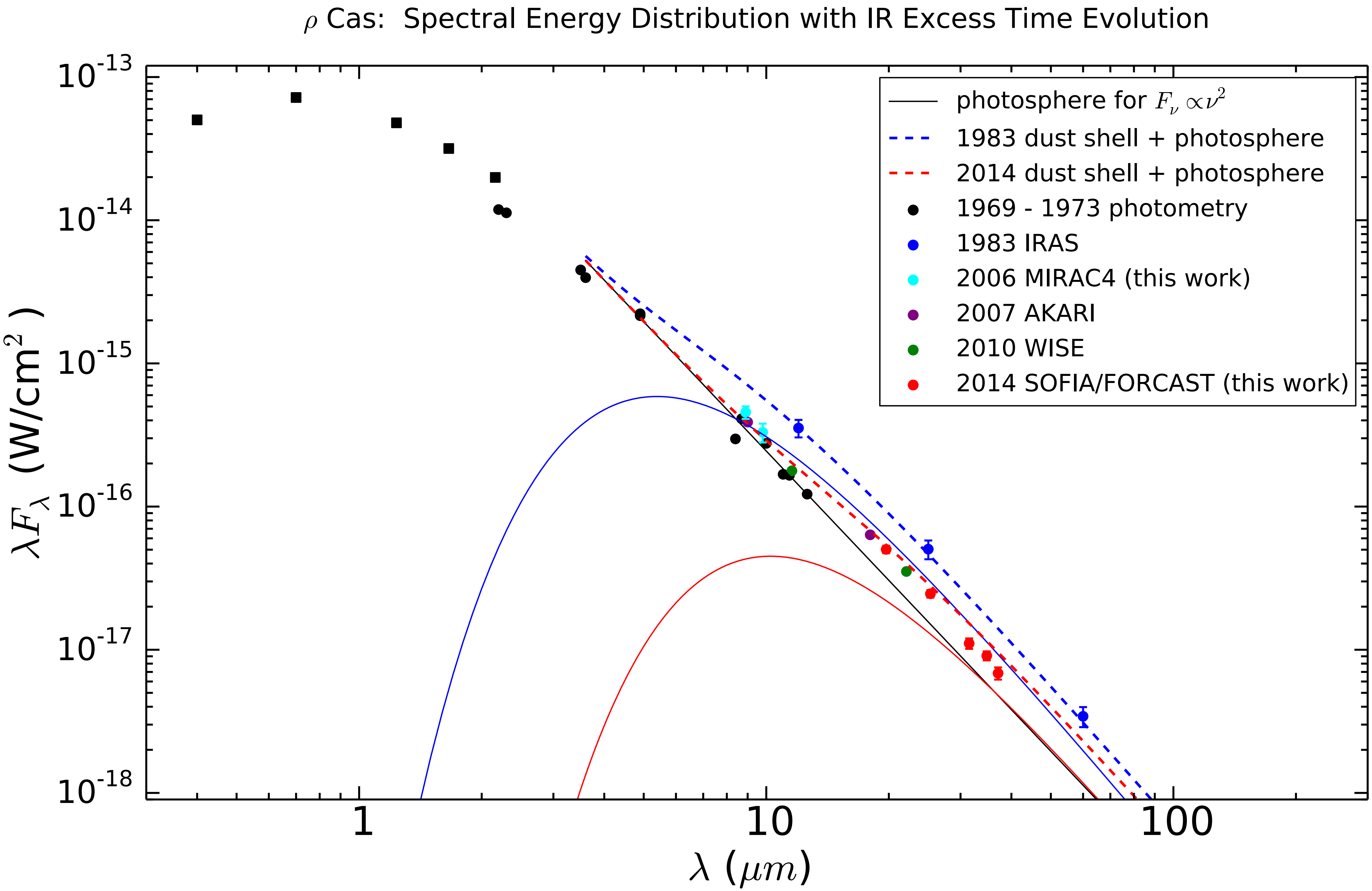

Shenoy et al. (2016)

SUMMARY & FUTURE WORK

- μ Cep: FORCAST resolved emission → declining $\dot{M}$,
  with $\langle \dot{M} \rangle \approx 4 \times 10^{-6}\ M_\odot$ / yr, over 13,000 yr
- VY CMa: discrete episodic ejections (Clump > $5 \times 10^{-3}\ M_\odot$),
  with $\langle \dot{M} \rangle \approx 6 \times 10^{-4}\ M_\odot$ / yr
- IRC + 10420: Order of magnitude change ~ 2000 yr ago
- FUTURE WORK: NML Cyg, VX Sgr, S Per, T Per, RS Per

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